

Measurement of an Excited Charmonium State and the Study of J/ψ Polarization in $p + p$ Collisions at $\sqrt{s} = 200$ GeV in PHENIX Experiment at RHIC

Marisilvia Donadelli for the PHENIX Collaboration

*University of Sao Paulo - Institute of Physics - Matao Street, alley R,187; Postcode 05508-900,
University campus Sao Paulo, Brazil*

Abstract

We report the $J/\psi \rightarrow e^+e^-$ and the $\psi' \rightarrow e^+e^-$ production cross sections in the PHENIX experiment at RHIC. The first measurements of the production cross sections of the ψ' and the ψ' over the J/ψ , will contribute to the clarification of the theoretical understanding of the J/ψ meson production. The inclusive J/ψ polarization through the same decay channel is also presented, showing a trend of slightly longitudinal polarization for $p_T < 5$ GeV/c.

Key words:

PACS:

1. Introduction

Charmonia are predominantly generated in hadronic collisions via gluonic diagrams and their production can be calculated in perturbative QCD, but the details of their hadronization process remain unclear. Color neutralization is a non perturbative process and several models have been proposed. Non relativistic QCD (NRQCD) calculations explained the J/ψ and ψ' direct production cross sections at CDF [1,2], but failed to predict their transverse polarization trend as p_T increases [3]. On the other hand, a new approach described in [4] seems to solve the underestimation of the experimental cross section predicted by the original color singlet models.

Email address: marisilvia.donadelli@gmail.com (Marisilvia Donadelli for the PHENIX Collaboration).

2. Charmonium signals at PHENIX Central Arms

At mid rapidities ($|y| \leq 0.35$) $J/\psi \rightarrow e^+e^-$ and $\psi' \rightarrow e^+e^-$ are measured by the central arm detectors which each cover $\Delta\phi = \pi/2$, and include an electromagnetic calorimeter (EmCal), drift chambers (DC) and a ring imaging cherenkov (RICH) [5]. Electron candidates are charged tracks identified by the RICH, with position and energy measured by the EmCal. The DC's measure the tracks deflection angles in a magnetic field to determine their momenta. Dielectron events must pass an additional trigger that requires matching hits between the EmCal and the RICH.

3. Charmonium cross sections

Figure 1 shows the invariant mass spectrum for dielectron pairs after subtracting the like-sign background. The mass window for the J/ψ is $[2.7-3.4] \text{ GeV}/c^2$ and for the ψ' is $[3.5-3.9] \text{ GeV}/c^2$. The mass spectrum was fit with line shapes generated from Monte Carlo simulation of continuum contribution (correlated D and B mesons and Drell-Yan), [6]. The external radiation was reproduced by the PHENIX Integrated Simulation Application code based on the GEANT3 [7] and the internal radiation was derived from the analytical formula described in [8] to account for radiative effects in the mass spectrum.

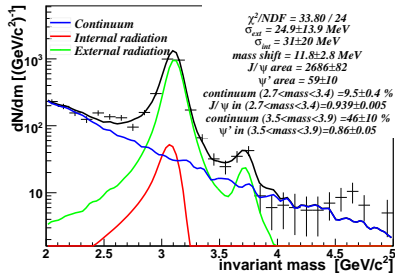


Fig. 1. Invariant mass distribution e^+e^- in the region of the J/ψ and ψ' peaks including all the continuum components.

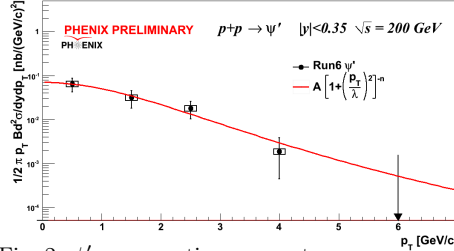


Fig. 2. ψ' cross section versus transverse momentum at mid rapidity.

Figure 2 shows the ψ' cross section versus transverse momentum at mid rapidity fitted with the function $d\sigma_{J/\psi}/dydp_T|_{y=0} = A/[1 + (p_T/\lambda)^2]^n$. The parameters A , λ and n were set free during the fit. Through numerical calculation from the data points one finds the J/ψ $\langle p_T^2 \rangle = 4.60 \pm 0.15$ (uncorr) ± 0.11 (corr) $(\text{GeV}/c)^2$ and the ψ' $\langle p_T^2 \rangle = 7.13 \pm_{-2.6}^{+2.0}$ (uncorr) ± 0.26 (corr) $(\text{GeV}/c)^2$ for $p_T < 7 \text{ GeV}/c$. The cross section for J/ψ (ψ') was obtained through,

$$\frac{B_{ee}}{2\pi p_T} \frac{d^2\sigma_\psi}{dp_T dy} = \frac{1}{2\pi p_T} \frac{n_\psi(p_T)}{\int L dt \epsilon(p_T) \Delta p_T \Delta y} \quad (1)$$

where B_{ee} is the charmonium branching ratio to the di-electron decays, n_ψ is the number of the particular ψ particle, ϵ is the overall efficiency including geometric acceptance, reconstruction and trigger efficiencies; Δy is the rapidity bin width, Δp_T is the p_T bin width and $\int L dt$ is the integrated luminosity. For J/ψ , $B_{J/\psi \rightarrow e^+e^-} \sigma_{J/\psi}|_{|y| < 0.35} = 41.0 \pm 0.9$ (stat) ± 4.9 (sys) nb, and for ψ' , $B_{\psi' \rightarrow e^+e^-} \sigma_{\psi'}|_{|y| < 0.35} = 0.88 \pm_{-0.20}^{+0.30}$ (stat) ± 0.12 (sys) nb for ($p_T < 7 \text{ GeV}/c$).

Figure 3 shows the ratio of the ψ' to J/ψ invariant cross sections versus transverse momentum and the comparison with HERA-B Collaboration result [10].

The ratio obtained for $p_T < 7$ GeV/c is 0.019 ± 0.005 (stat) ± 0.002 (sys) and the feeddown fraction of J/ψ from the ψ' is 0.086 ± 0.024 , in agreement with [11,12].

4. J/ψ polarization measurement

If we consider the decays of charmonium to a charged lepton-antilepton pair, then the angular distribution is given by the parametrized form:

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \lambda \cos^2\theta, \quad (2)$$

where θ is the angle of the positive lepton momentum in the charmonium center-of-mass frame (helicity frame) with respect to the momentum of the decaying particle in the laboratory frame. The parameter λ indicates absence of polarization ($\lambda = 0$), complete transverse polarization ($\lambda = 1$), and complete longitudinal polarization ($\lambda = -1$). J/ψ candidates were selected in the mass window $[2.9-3.2]$ GeV/ c^2 after same sign pairs background subtraction.

The acceptance corrected $\cos(\theta)$ distribution is the measured distribution divided by the acceptance obtained from simulation. The J/ψ polarization parameter result obtained for integrated p_T s: -9.6 ± 7.2 (stat) ± 3.9 (syst). Figure 4 shows the p_T dependent J/ψ polarization parameter which agrees with theoretical calculations that incorporate the s-cut channel contribution to the J/ψ hadroproduction at RHIC energies [4].

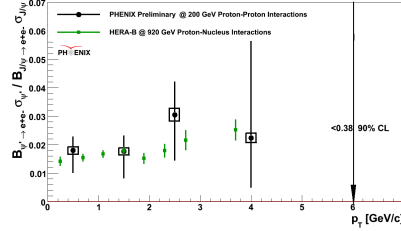


Fig. 3. p_T dependence of the ψ' to the J/ψ invariant cross section ratio. Comparison with HERA-B Collaboration Result [10].

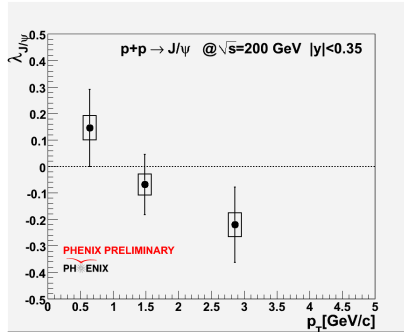


Fig. 4. p_T dependence of the polarization parameter.

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